

RETRIEVAL & VALIDATION OF RADIATIVE FLUXES AT THE OCEAN SURFACE WITH CERES

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1. INTRODUCTION

This paper, delivered at the WCRP/SCOR (World Climate Research Program/Scientific Committee on Ocean Research) Workshop on Intercomparison and Validation of Ocean-Atmosphere Flux Fields (Potomac, Maryland, 21-24 May 2001), describes the surface radiation budget (SRB) retrieved with CERES satellite instruments. Section 2 summarizes aspects of CERES and the status of CERES products. Section 3 addresses the accuracy of the SRB retrievals with CERES satellite data and the accuracy of SRB measurements with in situ sensors; and points out that few (in any) SRB measurements taken from research vessels and buoys meet standards of the WCRP Baseline Surface Radiation Network (BSRN). Section 4 describes the long-term CERES Ocean Validation Experiment (COVE), which does adhere to BSRN standards, and a July 2001 Chesapeake Lighthouse and Aircraft Measurements for Satellites (CLAMS) field campaign to improve satellite retrievals of the SRB, aerosols, and other quantities.

2. CERES (CLOUDS AND THE EARTH'S RADIANT ENERGY SYSTEM)

CERES (Wielicki et al., 1996) is the successor of the 1980s Earth Radiation Budget Experiment (ERBE, Barkstrom et al., 1989). CERES and ERBE have employed well-calibrated sensors for observing broadband shortwave (SW originally from the sun) and longwave (LW thermal infrared from the earth-atmosphere) radiances ($\text{W m}^{-2} \text{sr}^{-1}$). Both use empirically-based algorithms to estimate the SW and LW fluxes (irradiance in W m^{-2}) at the top of the atmosphere (TOA). ERBE did not use data from higher resolution cloud imagers (i.e., AVHRR) or NWP (i.e., NCEP analyses). This ERBE-like approach has been repeated with the first generation of CERES data; now available for January-August 1998 (low latitude precessing TRMM satellite) and for year 2000 (global, sun-synchronous Terra), and eventually after the launch of Aqua (late 2001?). CERES has more advanced processing that includes the retrieval of clouds and aerosols with high spatial resolution imagers (VIRS and MODIS, collocated within the coarser broadband footprints), NWP data (currently from ECMWF, later GEOS), and explicit radiative transfer calculations for each broadband footprint. Advanced products include cloud/aerosol properties and more accurate TOA fluxes (some now in archive); fast estimates of surface-only fluxes (in archive for some clear footprints); and vertical profiles of a consistent surface and atmospheric radiation budget (SARB, not yet in archive).

3. SURFACE RADIATION BUDGET

Figure 1 gives an example of preliminary SARB results. A modified Fu and Liou (1993) radiative transfer code has been coupled with a constraint (tuning) algorithm (Rose et al., 1997) and tested extensively (Charlock and Alberta, 1996; Charlock et al., 2001). Atmospheric constituents in Figure 1 have been retrieved and then tuned to bring computed fluxes closer to satellite observations. Ground-based radiation observations were here used for evaluation only (not for tuning). Cloud optical depth, areal coverage, and altitude are tuned for most footprints. In clear footprints, humidity, skin temperature, aerosols, and land surface albedo are tuned.

Computed and Observed Fluxes at Surface and TOA
TUNED FULL SKY
 CERES+VIRS TRMM – Daytime January 1998–21 ARM SGP Sites

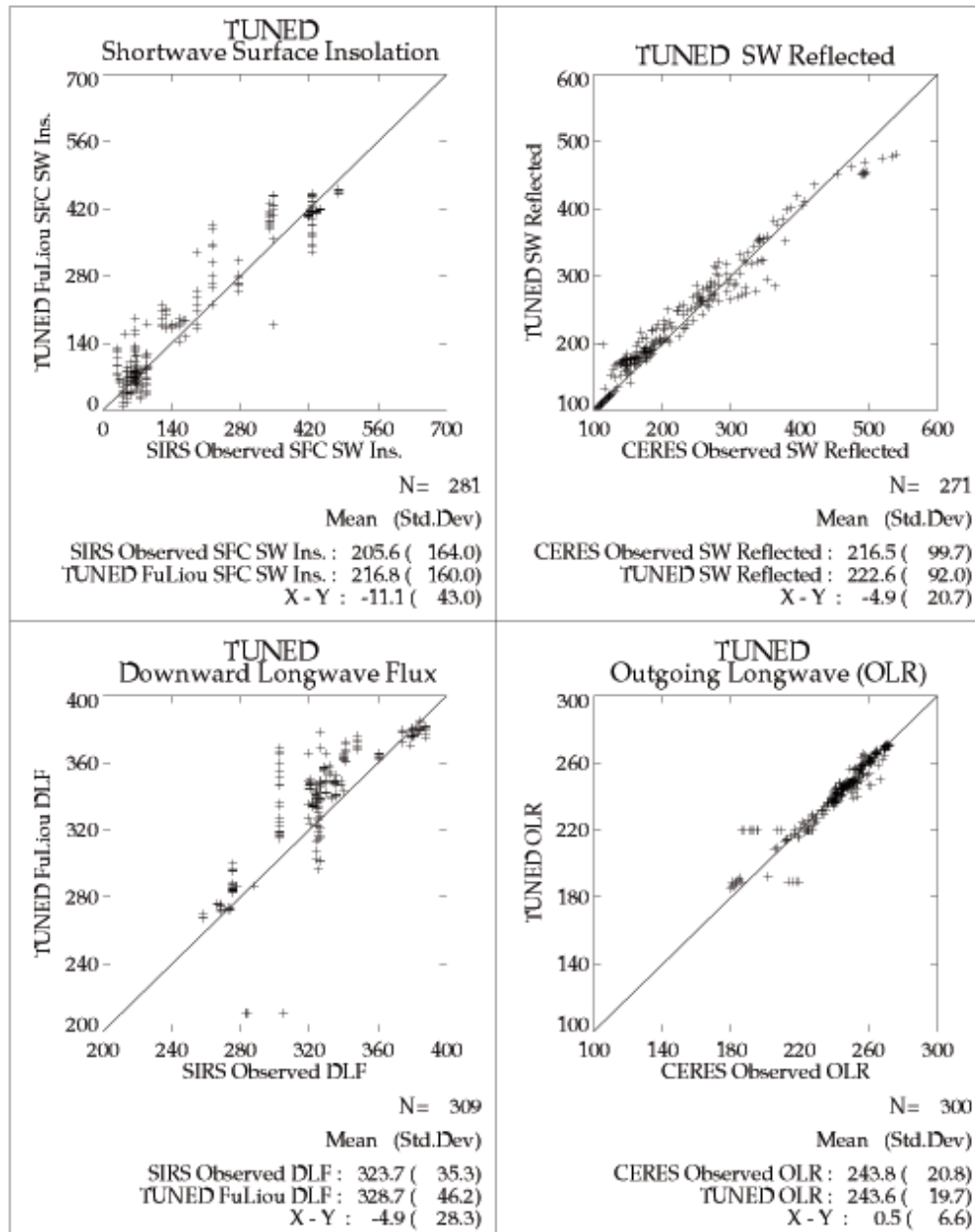


Figure 1 — Test of SARB at surface (left) and TOA (right) over Oklahoma and Kansas

CERES retrievals of the SARB are validated with the on-line CAVE (see Rutan et al., 2001 and www-cave.larc.nasa.gov/cave/), which provides easy access to observations at about 40 sites worldwide. At 21 ARM SGP sites in Oklahoma during January 1998 (Figure 1), the monthly mean discrepancies of retrieved and observed radiation approach the standards for observational error used by ERBE at TOA and by BSRN at the surface (Table 1). The box in Table 1 is taken directly from BSRN. Many CAVE sites subscribe to the strict BSRN protocols for operation and calibration. BSRN requires a stable observing platform (ships and buoys rock).

We regard the BSRN assessment of the accuracy for the best standard measurement of direct solar flux (1% or 2 Wm⁻², whichever is larger) as realistic; part of the protocol involves a trace to a reference calibration instrument. The assessment for the accuracy of surface LW flux in Table 1 is overly pessimistic; we regard the best pyrgeometers as accurate to within 5-10 Wm⁻². Note that for the important horizontal solar insolation (2 pi irradiance) at the surface, there is no instrument or procedure which has been accepted as the ultimate reference; there is no measurement of absolute truth for the diffuse component of insolation.

Table 1 - Key Radiation Accuracies and Forcings

Accuracy of top-of-atmosphere (TOA) ERBE observations:

Observed global annual net (SW-LW) ~ 5 Wm⁻²

Stated goal for regional monthly uncertainty ~ 6 Wm⁻²

Year-to-year fidelity (if continuous) ~ 1-2 Wm⁻² (CERES better by four)

Accuracy of surface observations:

Baseline Radiation Network (BSRN) operations Manual (WMO /TD-No. 879, 1998)

BSRN is a high quality standard to which the best stations may subscribe.

Ships/bouys do not meet BSRN standards for SW

Quantity at surface	Capability	Goal
Direct solar irradiance	1% or 2 Wm ⁻²	
Diffuse solar radiation	10 Wm ⁻²	4% or 5 Wm ⁻²
Global (SW) radiation	15 Wm ⁻²	2% or 5 Wm ⁻²
Reflected shortwave radiation	15 Wm ⁻²	5%
Downwelling longwave radiation	30 Wm ⁻²	5% or 10 Wm ⁻²
Upwelling longwave radiation	30 Wm ⁻²	5% or 10 Wm ⁻²

IPCC 1995 forcing by well-mixed anthropogenic gases +2.45 Wm⁻²

Direct forcing by anthropogenic aerosol at TOA ~—0.2 to —0.8 Wm⁻²

Indirect forcing by anthropogenic aerosol at TOA ~0.0 to —1.5 Wm⁻²

World Ocean heat storage from mid-1950s to mid-1990s

warming rate of 0.3 Wm⁻² (Levitus et al., 2000)

Geothermal heating ~0.06 Wm⁻² (Oort, 1992)

The accuracies for observations in Table 1 shed light on global systems like NWP Reanalyses which are often compared with observations. ERBE set a goal of 6 Wm⁻² accuracy for monthly mean observations in a 2.5 by 2.5 degree region (Table 1). But on a global annual mean (a looser condition than monthly regional), there is a difference of ~5 W m⁻², wherein ERBE says the earth absorbs significantly more SW than it emits in LW (OLR). From the long term ocean analysis of Levitus et al. (2000), earth is warming at only ~0.3 W m⁻². Note that 5 >> 0.3. If the globe were out of balance for a single year by 5 W m⁻², temperatures would change much more rapidly than during the (smaller than 5 W m⁻² global mean perturbations of the) El Chichon and Pinatubo eruptions. The 5 Wm⁻² imbalance reported by ERBE then flags certain limits of ERBE. And from that, we infer that the true regional, monthly error in ERBE is actually larger than the stated 6 Wm⁻². The actual fidelity of year to year observations (the accuracy of the year to year CHANGE) in ERBE is better at ~1-2 Wm⁻².

Returning to in-atmosphere considerations, we can assume that the current pyrgeometers (30 Wm⁻² stated in Table 1) are unable to monitor a small forcing such as that due to well-mixed anthropogenic gases (2.45 Wm⁻²). This LW issue is not a great concern, as the concentrations of well mixed gases can be measured very well by other means; and our knowledge of spectroscopy allows the forcing to be computed with confidence of 5 or 10%. The limitation of in-atmosphere SW radiometry is, however, a significant issue. In SW, the forcing is due to aerosols, and we surely cannot count and characterize aerosols nearly as well as well mixed gases. Our devices for counting aerosols in a column are basically narrowband radiometers — which are less accurate than the broadband instruments noted in Table 1. Hence estimates of aerosol radiative forcing to the surface and the atmosphere will likely be uncertain for

some time. More accurate satellite data and more realistic data on surface boundary conditions will improve estimates of aerosol forcing at TOA. Because of the absorption of SW by aerosols, anthropogenic direct forcing to the surface is considerably larger than at TOA.

4. RIGID SEA PLATFORM AND FIELD CAMPAIGN

The CERES Ocean Validation Experiment (COVE) is located 25km offshore from Virginia Beach on a rigid steel platform (water depth 11m) far from breaking surf. COVE makes continuous observations of radiation (as per BSRN), aerosol optical depth, and meteorological and wave parameters. Radiometers are placed 20-30m above the sea surface and accumulate only a small amount of spray. A SP1-A spectral photometer scans downward for ocean BDRF. The continuous, long-term COVE data is used to characterize ocean radiation at one point in terms of many variables; for example, the effect of wind direction, wind speed, wave swell height, sun angle, and aerosol optical depth on spectral BDRF.

A field campaign is needed to determine how effectively a single point (COVE) represents a larger area. The Chesapeake Lighthouse and Aircraft Measurements for Satellites (CLAMS), will be conducted at COVE during 10 July — 3 August 2001 by the CERES, MODIS, MISR, GACP, and GIFTS science teams. CLAMS will validate satellite-based retrievals of aerosols and SW flux; and measure radiation at the ocean surface to buttress new algorithms for retrieving ocean and atmosphere parameters with satellite data (i.e., those based on explicit treatments of scattering and absorption in BOTH media, as Jin and Stamnes, 1994, as well as the traditional Cox-Munk facets). Fixed wing aircraft in CLAMS include an ER-2, CV-580, Proteus, Cessna, OV-10, and a Learjet; COVE itself is serviced by helicopter. Information is on line at www-cave.larc.nasa.gov/cave/, as is much COVE data (starting fall 1999).

5. REFERENCES

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